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ASTROMETRIC PROPERTIES OF THE SCHMIDT
TELESCOPE OF THE BEIJING ASTRONOMICAL OBSERVATORY

by

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ASTROMETRIC PROPERTIES OF THE SCHMIDT TELESCOPE OF THE BEIJING ASTRONOMICAL OBSERVATORY

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ABSTRACT:

The astrometric properties of the 60/90/180 cm Schmidt telescope of the Beijing Astronomical Observatory have been investigated. One plate of the Pleiades cluster and another of the α Per moving cluster were measured by the Zeiss ASCORECORD measuring machine. The standard errors of measurement were $\pm 1.4\,\mu$ or $\pm 0.''15$ in x and $+1.5\,\mu$ or $\pm 0.''17$ in y.

The standard deviation of the computed volues using 10 plate constants in the entire field of $4.^\circ8$ diameter from the catalogue positions was $\pm 0.''38$ and in the field of $3.^\circ2$ diameter was $\pm 0.''34$ (averaged for right ascension and declination). No visible magnitude dependence was found.

I. Introduction

In photographic measurements of heavenly bodies, the functions that the Schmidt telescope can exhibit have been studied by many researchers [1-5]. The Schmidt telescope is high in optical power and can detect low stellar magnitudes so its efficiency in obtaining information is very high. From a photographic negative used with a 48-inch Schmidt telescope with 1h light exposure, one million or more star images can be obtained [6]. Therefore the telescope can locate large numbers of faint heavenly bodies, especially in locating such heavenly bodies outside the Milky Way galaxy corresponding to radio sources. Thus this telescope can contribute to making the coordinate system closer to an inertial-reference celestial sphere with radio sources outside the Milky Way as the fundamental framework. In addition, this telescope can also contribute to exploring for low-stellar-magnitude stars near the solar system, and to research on small heavenly bodies within the solar system.

By using the Schmidt telescope for photographic locations, there are several significant unique features: its principal lens is a spherical surface lens, therefore there is no optical axis. Under the situation with a similar caliber and focal length, the Schmidt telescope has greater clear field of view compared to other telescopes. Besides the curvature of field, the other three levels of image aberration are much smaller than those with other types of optical systems. Errors related to magnitude are the main factor affecting measurement precision in photographing heavenly bodies. Besides image spots as affecting measurement precision, coma aberration of the optical system has the effect of deviating the projective location of a star from its center-of-image spot. The brighter the star, the greater is its deviation. This is also the main reason leading to error in magnitude. The eyepiece of the Schmidt optical system has only one very thin corrective lens, approximating a flat optical plate. Therefore, its chromatic aberration is also very small, thus capable of improving the positional error due to different types of stellar spectra.

There are weak points that are difficult to overcome in the use of the Schmidt telescope in making measurements of heavenly bodies: 1. its short focal length, so that the precision loss is too high when converting from the coordinates on the negative to the celestial sphere coordinates. Secondly, the glass photographic negative is bent into a spherical surface during the photographic period, and the negative is restored to a flat surface when measurements are being made. This leads to the variation factor on the position of the star image on the developed plate that is difficult to anticipate.

By using measurements on the photographic plate and reducing the computations, the actual precision of the 60/90/180 Schmidt telescope at the Beijing Astronomical Observatory is obtained when measurements and positions are taken of heavenly bodies.

II. Observation and Measurements

For the Schmidt telescope at the Beijing Astronomical Observatory, the caliber of its corrective lens is 60cm; the caliber of its principal lens is 90cm; and its focal length is 180cm. The lens has a circular 4°.8 field of view. The dimensions of the negative plate is 16x16cm^2; and its scale of the negative plate is 114".1/mm. Refer to Table 1 for the situation of two photographic negative plates used.

TABLE 1

底 片 号 1	SD-48	SD-1645
拍摄日期 2	1965.9.27.	1982.11.19
天区 3	ηTau	αPer
底片中心 4	3^h40^m, +24°0′	3^h20^m, +49°41′
底片型号 5	Kodak DaO	Kodak 103_aO
露光时间 6	30min	5min
露光中心时刻 (北京时间) 7	0^h47^m	23^h10^m
天顶距 8	35°	10°
拍摄地点 9	沙河工作站 11	兴隆工作站 12
观测者 10	陈建生、黄永伟 13	郝象樑 14

KEY: 1 - number of negative plates 2 - date photographed 3 - heavenly region 4 - negative plate center 5 - model number of negative plate 6 - exposure time 7 - midpoint of exposure time (Beijing time) 8 - zenith distance 9 - photography locations 10 - observers 11 - Shahe work station 12 - Xinglong work station 13 - Chen Jiansheng and Huang Yongxiu 14 - Hao Xiangliang

The measurement of the photographic negative plate applied the Zeiss Ascorecord coordinate measurement instrument at Tianjin latitude station of the Beijing Astronomical Observatory. By using an ST-48 negative plate for measurements of 1932 stars; one measurement was conducted for each star only. The number of stars measured was 947, when using SD-1645 negative plates with four measurements for each star; in other words, one measurement was made for rotating the field-of-view prism of the measurement instrument at 0°, 90°, 180°, and 270°. The error of star positional measurements after the results of four measurements for each star (indicating the mean square error on the average value of four measurements, with the average taken for 946 stars) are:

E(x)=+/-1.4mu, corresponding to +/-0".154 in the celestial sphere
E(y)=+/-1.5mu, corresponding to +/-0".170 in the celestial sphere

III. Reference Stars

The reference stars are selected from the three following star catalogs:

A. In the star catalog published by H. Eichorn in 1970 [8], there are right ascensions and declinations of 502 fixed stars in the range 1°.5 x 1°.5 of eta Tau heavenly region. The epoch of the star catalog was obtained as 1955.0, from 14 negative plates photographed from a 26-inch reflective lens (scale 20".75/mm) at the Leander McCormick Astronomical Observatory, with a precision of 0".01. In the catalog, there are only 102 stars with proper motion; this was obtained from the star catalog published by Hertzsprung in 1947.

B. from the star catalog published by O. Heckmann in 1956 [9], there are only the positions and proper motions of 1379 fixed stars in the range of 5°.5x5°.0 in the alpha Per heavenly region. In the star catalog, the epoch is 1947.41; the positional error is +/-0".475; and the proper motion error is +/-0".044/year; when converted to the SD-1645 negative plate, the positional error of the observed epoch is +/-0".16.

TABLE 2

星表 2 / 底片号 1	A	B	C
SD-48	372	—	208
SD-1645	—	583	184

KEY: 1 - number of negative plates   2 - star catalog

C. In the ABK3 Star Catalog, the catalog epoch is 1958.5.

On the SD-48 negative plate, reference stars are selected from catalogs A and C. On the SD-1645 negative plate, fixed stars are selected from catalogs B and C. Table 2 shows the number of stars selected.

IV. Projection Model

When photographing with the Schmidt telescope, the 1mm thick glass negative plate was bent under mechanical pressure, to form a spherical surface (the center of the negative plate was concave, by 1.8mm, due to bending, for the OD160mm negative plate at f=1.8m) with radius equal to the focal length of the optical lens. During measurement, however, the negative plate was restored to a flat surface. It is considered that the bending deformation of the negative surface is subject to the following rule: (1) the geometric center O of the negative plate is the symmetric point of bending deformation; (2) the diametral length of the symmetric point remains constant; that is, the large arc length *OS on the celestial sphere is equal to the straight-line length OS on the flat surface; (3) the orientation angle remains constant; that is, the spherical angle *theta on the celestial sphere is equal to the *theta on the flat plane. Based on this rule, the projection model between the rectangular coordinates X

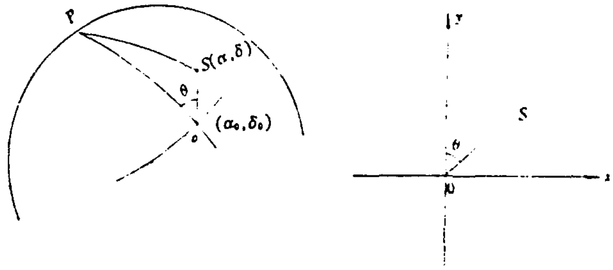

Fig. 1.

and Y on the flat plane on the negative plate, as well as the coordinates alpha and delta of the equator in the celestial sphere. The following conversion formulas can be derived:

$$\left.\begin{aligned} X &= \frac{q}{\sin q}\cos\delta\sin(\alpha-\alpha_0)\cdot\frac{206264.8}{R_M}, \\ Y &= \frac{q}{\sin q}(\cos\delta_0\sin\delta - \sin\delta_0\cos\delta\cos(\alpha-\alpha_0))\cdot\frac{206264.8}{R_M}, \\ \cos q &= \sin\delta_0\sin\delta + \cos\delta_0\cos\delta\cos(\alpha-\alpha_0). \end{aligned}\right\} \quad (1)$$

$$\left.\begin{aligned} \sin\delta &= \sin\delta_0\cos(R_M\cdot q') + Y\cos\delta_0\frac{\sin(R_M\cdot q')}{q'}, \\ \sin\Delta\alpha &= X\frac{\sin(R_M\cdot q')}{q'\cos\delta}, \\ \alpha &= \alpha_0 + \Delta\alpha, \\ q' &= \sqrt{X^2+Y^2}. \end{aligned}\right\} \quad (2)$$

In the equations, $alpha_0$ and $delta_0$ are right ascension and declination of the geometric center on the negative plate; R_M is the scale of the negative plate, with angular second per mm as the unit; the unit for **q** is the radian; and the unit for X and Y is the millimeter.

V. Reductive Computations

The same method as Anderson's is used for reductive computation of the SD-48 negative plate [3]; according to the conventional coordinate conversion formula [10] of tangent plane, the standard coordinates X and Y are derived for each reference star. With respect to the measurement coordinates x and y for all star images, bending compensation of the negative plate is applied:

$$dx = \frac{1}{3}x(x^2 + y^2),$$

$$dy = \frac{1}{3}y(x^2 + y^2).$$

then, by using the reductive formula for constant 10 negative plate:

$$\begin{cases} \Delta x = a + bx + cy + px^2 + qxy + p'(3x^2 + y^2) + q' \cdot 2xy, \\ \Delta y = d + ex + fy + pxy + qy^2 + p' \cdot 2xy + q'(3y^2 + x^2) \end{cases}$$

to form 2n conditional equations (n is the number of reference stars) to be solved by using the least-squares method. By using the derived negative constant, the star positions are calculated for comparison with the positions in the star catalog. In the case when the difference value along a coordinate direction exceeds three times the average error, this star is discarded to again form new equation sets for repeated solution until the final negative plate constant is derived.

On the SD-1645 negative plate, Eq. (1) is used to calculate the X and Y of the reference star, without compensation for the measurement coordinates due to negative plate bending. Then, the same reductive method as that of the SD-48 negative star is applied. The computational work was performed on VT-60 electronic computers at the Tianjin latitude station of the Beijing Astronomical Observatory, and the Institute of Geology of the Chinese Academy of Sciences, by using the large sparse matrix method. With respect to a group of reference stars on the SD-48 negative plate, repeated calculations were conducted by using the same method of processing the SD-1645 negative plate. It was proved that the results are the same as when using both processing methods (see Table 4).

VI. Results

After selecting with iterative substitution of the selected stars in the catalog, the number of stars obtained is shown in Table 3. Based on the final calculated negative star constant, star positions were calculated. By comparison with the positions in the star catalog, the average deviation *eta and the mean-square error *epsilon along one coordinate direction are listed in Table 4. n is the number of stars on the average. The star number ratio between the reference stars and the measured stars is 1:3. The selection method is as follows: based on the sequential arrangement in the star catalog, one star is chosen as the reference star in a group of three stars; the others are considered as the measured stars. One can see that the reference stars are randomly distributed; and the measured stars are not computed in the negative plate constant. In the event that there are no measured stars, all the stars in the catalog are considered as reference stars, with their *eta and *epsilon values being listed. In the stars selected from the catalog, the number of discarded stars averages 14.5% on the SD-48 negative plate; and 1.8% on the SD-1645 negative plate. The reason is that only one measurement is made for each star on the SD-48 negative plate; so that the occasional error is higher. With respect to the Eichorn Star Catalog, it is the same with or without applying the proper motion precision; this indicates that the proper motion data are inaccurate. All the bright stars (including alpha Per, m_{pg}=2.3) were included in the calculations; the result is compared with the result when only such stars with m_{pg} greater than or equal to 8.0 were taken, the precision is not improved. With respect to those stars in the center or the fringe of the field of view, there are minor precision differences. By using SD-1645 negative plates, and reference stars selected from the Heckmann Catalog, the obtained positional precision of the measured stars was as follows: after subtracting the error of the star catalog per se, a mean-square error along the coordinate direction is +/-0".38 (for star number n=429) in the O\4°.8 range of the entire field of view, and it is +/-0".34

(n=225, m_{pg} greater than or equal to 8.0) in the O\3°.2 range.

TABLE 3

星表 2 / 底片号 1	A	B	C	共计 3	星等范围 4
SD-48	316	—	178(其中 42 星与 A 相重) 5	452	$m_{pg} \leqslant 14.5$
SD-1645	—	572	181(其中 170 星与 B 相重) 6 总计 7	583 1035	$m_{pg} \leqslant 12.2$

KEY: 1 - number of negative plates 2 - star catalog 3 - total 4 - range of stellar magnitudes 5 - 178 (42 of the 178 overlaps with A) 6 - 181 (170 out of the 181 overlap with B). 7 - grand total

VII. Conclusions

The good points of using the 60/90/180 Schmidt telescope at the Beijing Astronomical Observatory to photograph heavenly bodies for measurement include the higher limit of faint stars that can be observed and higher observational efficiency, good star image quality in large field of view range, and the measurement precision on negative plates can be +/-1.5mu (corresponds to +/-0".17 on the celestial sphere), and almost no error for stellar magnitude. The slight reduction of precision at the fringe of the field of view is possibly due to the residual coma aberration or the bending model of the negative plate. Because of short focal length, bending deformation of the negative plate, and the lacking of certain numbers of reference stars with proper quality, the positional precision is limited. The precision values obtained in the article are as follows: in the entire field of view O\4°.8 range, it is +/-0".38; in the O\3°.2 range, it is +/-0".34.

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Beijing Astronomical Observatory.

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TABLE 4

1 底片号	视场及选星范围 2	Eichhorn 星表 3						Heckmann 星表 3						AGK3 星表 3					
		4 定标星			被测星 5			定标星 4			被测星 5			定标星 4			被测星 5		
		n	η	ε	n	η	ε	n	η	ε	n	η	ε	n	η	ε	n	η	ε
SD-48	⌀4°.8													178	0".497	0".599	—	—	—
	⌀2°.0													62	0.466	0.578	—	—	—
	1°.5× 1°.5	316*	0".407	0".499	—	—	—												
	1°.5× 1°.5	79	0.433	0.537	237	0".408	0".501												
	1°.5× 1°.5	69**	0.421	0.515	—	—	—												
SD-1645	⌀4°.8							572	0".318	0".403	—	—	—	181	0".434	0".547	—	—	—
	⌀4°.8							143	0.319	0.405	429	0".328	0".416	46	0.415	0.573	135	0".456	0".560
	⌀4°.8 $m_{pg}\geqslant$ 8.0							132	0.314	0.400	396	0.326	0.413	33	0.448	0.606	99	0.470	0.596
	⌀3°.2 $m_{pg}\geqslant$ 8.0							75	0.295	0.393	225	0.298	0.374	18	0.332	0.489	51	0.448	0.573

KEY: 1 - number of negative plates 2 - field of view and range of stars selected 3- star catalog 4 - reference stars 5 - measured stars

* - this group of stars--computations were made by using two processing methods, with the same results.

** - these are 69 stars with proper motion as selected out of 316 stars.

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